TAMPINES MERIDIAN JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATION

CANDIDATE NAME	
CIVICS GROUP	

H2 CHEMISTRY — **9729/04**

Paper 4 Practical — **3 September 2025**

2 hours 30 minutes

Candidates answer on the Question Paper.

READ THESE INSTRUCTIONS FIRST

Write your name and Civics Group in the spaces at the top of the page.

Give details of the practical shift and laboratory where appropriate, in the boxes provided.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the question paper.
The use of an approved calculator is expected, where appropriate.

You may lose marks if you do not show your working or if you do not use appropriate units.

Qualitative Analysis Notes are printed on pages 21 and 22.

The number of marks is given in brackets [ ] at the end of each question or part question.

Shift
Laboratory

For Examiner's Use	
1	/ 10
2	/ 19
3	/ 17
4	/ 9
Total	**/ 55**

Answer **all** questions in the spaces provided.

1 Qualitative analysis tests involving solid iron(III) chloride

FA 1 is a solution containing iron(III) chloride, $FeCl_3.nH_2O$

FA 2 is a solution containing an unknown $\mathbf{L^-}$ ligand

Carry out the following tests. Record your observations in Table 1.1.

Unless otherwise stated, the volumes given in Table 1.1 are approximate and should be estimated rather than measured.

Test and identify any gases evolved.

If there is no observable change, write **no observable change.**

Table 1.1

		Test	Observations
(a)	**(i)**	Add about 6 cm depth of **FA1** into a test tube. Add aqueous silver nitrate in excess. Filter the mixture. Separate the filtrate into four test tubes for **(iii)**, **(iv)**, **(v)** and **(vi)**.	
	(ii)	Place the filter funnel containing the residue on a new test tube, add aqueous ammonia over the residue and collect the filtrate. To this filtrate, add nitric acid dropwise until no further changes.	
	(iii)	To the first test tube containing the filtrate from **(i)**, add 2 cm^3 of hydrogen peroxide. Observe the mixture until no further changes are seen.	

	(iv)	To the second test tube containing the filtrate from **(i)**, add an equal volume of aqueous sodium hydroxide. Then add 2 cm^3 of hydrogen peroxide. Observe the mixture until no further changes are seen.	
	(v)	To the third test tube containing the filtrate from **(i)**, add 1 cm^3 of **FA 2**.	
	(vi)	To the last test tube containing the filtrate from **(i)**, add half a spatula of iron filings. Then add an equal volume of hydrochloric acid. Dispose the reaction mixture once observations are completed to prevent gas build up.	

M1

M2

M3

M4

M5

[5]

(b) **(i)** With the aid of the following equilibrium equations, explain the observations obtained in Test **(ii)** when nitric acid was added to the filtrate.

$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$ -- Equilibrium 1

$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq)$ -- Equilibrium 2

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.... [1]

M6

(ii) In the presence of a strong base, hydrogen peroxide reacts with OH^- to form HO_2^-.

electrode reaction	**$E^\ominus$/V**
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$Fe(OH)_3 + e^- \rightleftharpoons Fe(OH)_2 + OH^-$	–0.56
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0.68
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$O_2 + H_2O + 2e^- \rightleftharpoons HO_2^- + OH^-$	–0.08

With reference to the electrode potential given above, calculate the overall $E^\ominus$ values for the reactions in Tests **(iii)** and **(iv)** respectively.

Hence, account for the difference in the rate of effervescence produced when hydrogen peroxide was added in Tests **(iii)** and **(iv)**.

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.... [2]

M7
M8

(iii) Based on your observation in Test **(v)**, state the type of reaction that has occurred.

.... [1]

M9

(iv) In Test **(vi)**, a comproportionation reaction occurred, where two species of the same element undergoes a redox reaction to form the same product. Write an ionic equation to represent the reaction.

.... [1]

M10

[Total: 10]

2 Determination of water of crystallisation in a hydrated iron(III) salt

Iron(III) chloride solutions are often used as a coagulant to remove impurities in sewage and industrial waste.

FA 3 is hydrated iron(III) chloride with the formula $FeCl_3.nH_2O$. The addition of excess zinc to a solution of **FA 3** converts the Fe^{3+} ions to Fe^{2+} ions. The amount of Fe^{2+} ions can then be determined quantitatively by titration against a standard solution of potassium manganate(VII), $KMnO_4$. The reaction between MnO_4^- and Fe^{2+} is as shown below.

$$5Fe^{2+} + MnO_4^- + 8H^+ \longrightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

In this experiment, you are to prepare a standard solution using **FA 3** and perform titrations to determine the value of *n*, the water of crystallisation in **FA 3**.

You are provided with the following:

FA 3 is solid hydrated iron(III) chloride, $FeCl_3.nH_2O$

FA 4 is 0.500 mol dm^{-3} dilute sulfuric acid, H_2SO_4

FA 5 is 0.0200 mol dm^{-3} potassium manganate(VII), $KMnO_4$

Zinc powder

(a) Preparation of standard solution of hydrated iron(III) salt

1. Weigh the capped container with **FA 3**. Record the mass.
2. Transfer all the **FA 3** measured into a 250 cm^3 beaker. Reweigh the weighing bottle and record its mass. Determine and record the mass of **FA 3** transferred.
3. Use a 100 cm^3 measuring cylinder to add 100 cm^3 of **FA 4** to the beaker. Stir the mixture with a glass rod to dissolve all the solid.
4. Transfer the solution into a 250 cm^3 volumetric flask. Rinse the beaker with deionised water and pour the washings into the volumetric flask.
5. Make up to the 250 cm^3 mark with deionised water, stopper and mix thoroughly by inverting the flask several times.
6. Label the resultant solution **FA 6**.

(b) Preparation of Fe^{2+} solution from FA 6

7. Use a 100 cm^3 measuring cylinder to transfer 100 cm^3 of **FA 6** into a 250 cm^3 beaker.
8. Add all the zinc powder in the container into the beaker. Continuously stir the reaction mixture for 5 minutes.
9. Filter the mixture into a **dry** 250 cm^3 conical flask provided using **dry** filter paper and filter funnel. Ignore any reaction that may still be taking place.
10. Label the filtrate as **FA 7**. Proceed to **(c)** once you have collected sufficient filtrate.

[Turn Over

(c) **Titration of FA 7 against FA 5**

11. Fill the burette with **FA 5** solution.
12. Use a 10 cm^3 pipette to transfer 10.0 cm^3 of **FA 7** into a 250 cm^3 conical flask.
13. Use a 10 cm^3 measuring cylinder to add 10.0 cm^3 of **FA 4** to this flask.
14. Titrate the reaction mixture in the conical flask with **FA 5** from the burette until the appearance of the first permanent orange colour.
15. Record your titration results, to an appropriate level of precision, in the space below.
16. Repeat steps 12 to 15 until consistent results are obtained.

Results

M11
M12
M13
M14

[4]

(i) From your titrations, obtain a suitable volume of **FA 5**, to be used in your calculations. Show clearly how you obtained this volume.

M15
M16
M17

volume of **FA 5** = ………………………………… [3]

(ii) Calculate the amount of Fe^{2+} in 10.0 cm^3 of **FA 7.**

M18

amount of Fe^{2+} in 10.0 cm^3 of **FA 7** = ………………………………… [1]

(iii) In step 8, an excess of zinc was added to convert the Fe^{3+} to Fe^{2+}. Calculate the amount of Fe^{3+} in 250 cm^3 of **FA 6**.

M19

amount of Fe^{3+} in 250 cm^3 of **FA 6** = ………………………… [1]

[Turn Over

(iv) Use your answer from **(iii)** to calculate the M_r of the hydrated iron(III) chloride, $FeCl_3.nH_2O$, in **FA 3**.

M_r of the hydrated iron(III) chloride = …………………………

Hence, deduce the value of n, the water of crystallisation in the hydrated iron(III) chloride.

[A_r: Fe, 55.8; C*l*, 35.5; O, 16.0; H, 1.0]

M20
M21
M22
M23
M24

n = ………………………….. [5]

(d) In step 10, excess zinc was filtered off before the titration of **FA 7** against **FA 5** to avoid any possible reaction between zinc and **FA 5**.

Suggest another reason why it was necessary to filter off the excess zinc metal, and what effect failing to do so would have on the titre values.

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M25

(e) A student carried out the experiment and obtained a **FA 5** titre volume of 10.00 cm^3 for the end-point. The absolute uncertainties associated with some of the apparatus used in the experiment are given below.

10.00 cm^3 pipette	$\pm$0.02 cm^3
50.00 cm^3 burette	$\pm$0.05 cm^3

(i) Use the data above to calculate the percentage uncertainty associated with each apparatus.

[1] M26

(ii) The percentage uncertainty associated with the use of the measuring cylinder is 2.00 %. Suggest why the percentage uncertainty associated with the use of the measuring cylinder is not considered when determining the overall percentage uncertainty of the experimental procedure.

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…………………………………………………………………………………………… [1] M27

(f) **(i)** Suggest how the titration would be affected if 10.0 cm^3 of water was added instead of **FA 4** in step 13.

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…………………………………………………………………………………………… [1] M28

(ii) Hydrogen peroxide is also able to oxidise the Fe^{2+} ions in an acidic medium. However, hydrogen peroxide is not a suitable replacement for potassium manganate in this experiment. Suggest a reason for this.

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…………………………………………………………………………………………… [1] M29

[Total: 19]

[Turn Over

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3 **Determination of the enthalpy change of neutralisation, ΔH_{neut} between a strong acid, H_aX and NaOH(aq).**

FA 8 is 1.00 mol dm^{-3} of strong acid, H_aX.
FA 9 is 1.60 mol dm^{-3} of sodium hydroxide, NaOH.

The enthalpy change of neutralisation is the heat evolved when one mole of water is formed during a neutralisation reaction as shown in the equation below.

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

You will perform a series of experiments by mixing different volumes of **FA 8** and **FA 9** while keeping the total volume of the reaction mixture to be constant. You will determine the temperature change, ∆T, for each reaction and plot a graph of temperature change, ∆T, against volume of **FA 8** used.

The maximum amount of heat is evolved when the acid present is exactly neutralised by the alkali added. You will then analyse the results graphically to determine the equivalence volume of the reaction and hence calculate the value of the enthalpy change of neutralisation, ΔH_{neut}.

For the experiment, you will calculate and record the average initial temperature, T_{avg}, before the reaction occurs when the **FA 8** and **FA 9** are mixed.

Average temperature, T_{avg}, can be obtained by using $T_{avg} = \frac{T_{FA8}+T_{FA9}}{2}$

Temperature change, ΔT, can be obtained by using $\Delta T = T_{max} - T_{avg}$

In an appropriate format in the space provided on the next page, prepare a table to record the data for each experiment to an appropriate level of precision:

- all measurements of volumes used,
- T_{max} and the temperature change, ΔT.

(a) Procedure

1. Measure the initial temperature of **FA 8** in the reagent bottle using the thermometer. Record this temperature as T_{FA8}. Wash and dry the thermometer.
2. Repeat step 1 for **FA 9**. Record this temperature as T_{FA9}. Determine T_{avg} using the recorded values of T_{FA8} and T_{FA9}.
3. Place a clean and dry polystyrene cup inside a second polystyrene cup which is placed in a 250 cm^3 glass beaker to prevent the cups from tipping over.
4. Using a 50 cm^3 measuring cylinder, measure 10.0 cm^3 of **FA 8** and transfer the **FA 8** solution into the polystyrene cup.
5. Using a 50 cm^3 measuring cylinder, measure 40.0 cm^3 of **FA 9** and transfer the **FA 9** solution into the polystyrene cup containing **FA 8**.
6. Using the thermometer, stir the reaction mixture in the polystyrene cup. Measure and record the maximum temperature reached, T_{max}.
7. Discard the contents of the polystyrene cup. Wash and dry the polystyrene cup and the thermometer.

Repeat steps 1 to 7 using 15.0 cm^3, 20.0 cm^3, 25.0 cm^3, 30.0 cm^3 and 35.0 cm^3 of **FA 8**, each time using an appropriate volume of **FA 9** so that the total volume of each mixture is kept constant.

Results

M30
M31
M32

[3]

(b) Using the data obtained, plot a graph of ΔT against volume of **FA 8** added.

Draw two best-fit straight lines for the points plotted, and extrapolate both lines to find

- the temperature change at equivalence point, ΔT_{eq}.
- the volume of **FA 8** added to completely neutralise **FA 9**.

ΔT_{eq} = ...

volume of **FA 8** required for complete neutralisation = ... [5]

M33
M34
M35
M36
M37

(c) **(i)** Calculate the volume of **FA 9** required for complete neutralisation. Hence calculate the amount of H_aX in **FA 8** and NaOH in **FA 9** required for complete neutralisation.

volume of **FA 9** required for complete neutralisation = …………………

amount of H_aX in **FA 8** = ……………………........................

M38

amount of NaOH in **FA 9** = ……………………........................ [2]

M39

(ii) Hence, determine the value of *a* and deduce a possible identity for H_aX.

value of *a* = ……………………......... [1]

M40

possible identity of H_aX = ……………………......... [1]

M41

(d) Calculate the enthalpy change of neutralisation, H_{neut}, for the reaction between H_aX and NaOH.

Assume that the specific heat capacity of the reaction mixture is 4.18 J g^{-1} K^{-1} and its density is 1.00 g cm^{-3}.

M42
M43

ΔH_{neut} = ... [2]

(e) In another experiment, **FA 9** was replaced by a solution of methylamine, CH_3NH_2, a weak monoacidic base of equal concentration. State and explain the effect on the following.

- ΔT_{eq}

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- volume of **FA 8** required

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.... [3]

M44
M45
M46

[Total: 17]

4 Planning

When potassium manganate(VII) reacts with sodium ethanedioate and sulfuric acid, a redox reaction occurs as shown below:

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \longrightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$ —— **reaction 1**

A product that is generated during the course of the reaction and helps to speed up the reaction rate is known as an autocatalyst. The autocatalyst for the above reaction is Mn^{2+}.

The kinetics of this reaction can be investigated by determining the concentration of MnO_4^- over the course of the reaction in a continuous monitoring experiment. Fixed aliquots (portions) of the reaction mixture are withdrawn at regular time intervals and added to an excess of potassium iodide.

The MnO_4^- in the aliquots reacts with excess iodide as shown below.

$$2MnO_4^- + 10I^- + 16H^+ \longrightarrow 2Mn^{2+} + 5I_2 + 8H_2O$$ —— **reaction 2**

The amount of iodine formed can then be determined by titration with the sodium thiosulfate solution as shown below.

$$I_2 + 2S_2O_3^{2-} \longrightarrow 2I^- + S_4O_6^{2-}$$ —— **reaction 3**

The volume of sodium thiosulfate used can then be used to determine the concentration of MnO_4^-.

(a) In reaction 1, both sodium ethanedioate and sulfuric acid are used in large excess. Explain the purpose of using a large excess of these solutions.

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.... [1]

M47

(b) Using the information given above, you are required to write a plan to investigate the kinetics of the autocatalytic experiment via the determination of the concentration of MnO_4^- at regular timed intervals.

You may assume that you are provided with the following:

- 25 cm^3 of 0.0500 mol dm^{-3} potassium manganate(VII), $KMnO_4$
- 0.500 mol dm^{-3} sodium ethanedioate, $Na_2C_2O_4$
- 1.00 mol dm^{-3} sulfuric acid, H_2SO_4
- 0.200 mol dm^{-3} potassium iodide, KI
- **M** mol dm^{-3} $Na_2S_2O_3$
- starch indicator
- stopwatch
- apparatus and chemicals normally found in a school or college laboratory.

Your plan should include:

- using the 25.0 cm^3 of $KMnO_4$ provided, justification for the volume of the remaining reactants to be used in **reaction 1**, so that a minimum of **6 aliquots of 10 cm^3** of the reaction mixture can be withdrawn
- determining a suitable concentration for the sodium thiosulfate, $Na_2S_2O_3$, to be used
- details of the apparatus you would use
- details of the experimental procedure, in particular the preparation of the reaction mixture and the titration with $Na_2S_2O_3$
- an outline of the results to be recorded and a sketch of the expected graph you would obtain

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M48

M49

M50

M51

M52

M53

M54

M55

[8]

[Total: 9]

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Qualitative Analysis Notes

[ppt. = precipitate]

(a) Reactions of aqueous cations

cation	*reaction with*	
	NaOH(aq)	NH_3(aq)
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	ammonia produced on heating	
barium, Ba^{2+}(aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca^{2+}(aq)	white ppt. with high [Ca^{2+}(aq)]	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II) Cu^{2+}(aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II) Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt., rapidly turning brown on contact with air insoluble in excess	off-white ppt., rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

(b) Reactions of anions

anion	*reaction*
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives pale cream ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; NO liberated by dilute acids (colourless NO (pale) $\rightarrow$ brown NO_2 in air)
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acid)
sulfite, SO_3^{2-}(aq)	SO_2 liberated with dilute acids; gives white ppt. with Ba^{2+}(aq) (soluble in dilute strong acid)

(c) Test for gases

gas	*tests and test result*
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns aqueous acidified potassium manganate(VII) from purple to colourless

(d) Colour of halogens

halogen	*colour of element*	*colour in aqueous solution*	*colour in hexane*
chlorine, Cl_2	greenish yellow gas	pale yellow	pale yellow
bromine, Br_2	reddish brown gas/liquid	orange	orange-red
iodine, I_2	black solid / purple gas	brown	purple